Chemical anomalies in globular cluster red giant stars and the "second parameter" problem

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Abstract: We present the evolution of low mass and low metallicity RGB models computed under the assumption of deep mixing between the convective envelope and the hydrogen burning shell. We discuss the helium enrichment of the envelope which is necessary or allowed to achieve or to keep consistency with the observations, and conclude on the possible connection between chemical anomalies in red giants and the horizontal branch morphology in globular clusters.

1 A possible connection between the chemical anomalies in RGB stars and the globular cluster HB morphology

The anomalies in elements participating in the CNO-, NeNa- and MgAl-cycles observed in globular cluster red giants (see Sneden in this Volume for a review) are unexplained in canonical low-mass star evolution theory and indicate effects beyond the standard picture. While some data require a primordial origin, part of the observations can be explained by a purely evolutionary picture which implies a non standard mixing process inside the low mass red giants (see Weiss et al. 1999 and references therein). Depending on its depth and efficiency, this mechanism may modify the evolution on the red giant branch (RGB) and shape the horizontal branch (HB) morphology, as suggested by Langer & Hoffman (1995) and discussed by Sweigart (1997). Basically, important helium enhacement in the envelope due to very deep mixing would induce larger luminosity and stellar winds on the RGB, resulting in a bluer position on the HB than in the case without additional mixing.

In order to test the possible connection between the chemical anomalies along the RGB and the HB morphology, we have computed full stellar evolutionary sequences which include deep mixing affecting both the hydrogen/helium structure of the stellar models and the distribution of the elements participating in the ONeNa-cycle. This is the first attempt to cover the problem in a consistent way, i.e., to treat the transport of helium (which affects the stellar structure) and of the other isotopes simultaneously.

2 Stellar models including deep mixing

The method used for the present computations is described in details in Weiss et al. (1999). We consider a star of initial mass $0.8M_\odot$ and of initial composition Y=0.25, Z=0.0003. Full evolutionary sequences are calculated with the Garching code under the assumption of deep mixing between the hydrogen burning shell and the convective envelope. We do not focus on the nature of the deep mixing mechanism. It is supposed to start at the RGB bump (Sweigart & Mengel 1979, Charbonnel 1994, Charbonnel et al. 1998), and it is treated as a diffusive process with parametrized values for the diffusive constant (D_{mix}) and for the penetration depth (ΔX_{mix} which relates to the decrease in hydrogen content and corresponds to a normalized mass coordinate δM_{mix} within the shell). Mass loss is taken into account according to Reimers's (1975) prescription. The different sets of parameters (D_{mix}, ΔX_{mix}) used in the computations lead to various degrees of envelope helium enrichment. They consequently lead to higher luminosity and lower stellar mass M_{tip} at the RGB tip than in the standard case. Typically, M_{tip} can be as low as $0.56M_\odot$, instead of $0.798M_\odot$ in the standard case (see in Weiss et al. 1999 for a complete description).

These models with various degrees of mixing are then used as background models for detailed nucleosynthesis computations in a post-processing way, as in Denissenkov & Weiss (1996). We show in Figure 1 the helium enrichment of the envelope predicted in the post-processing computations for different mixing prescriptions.

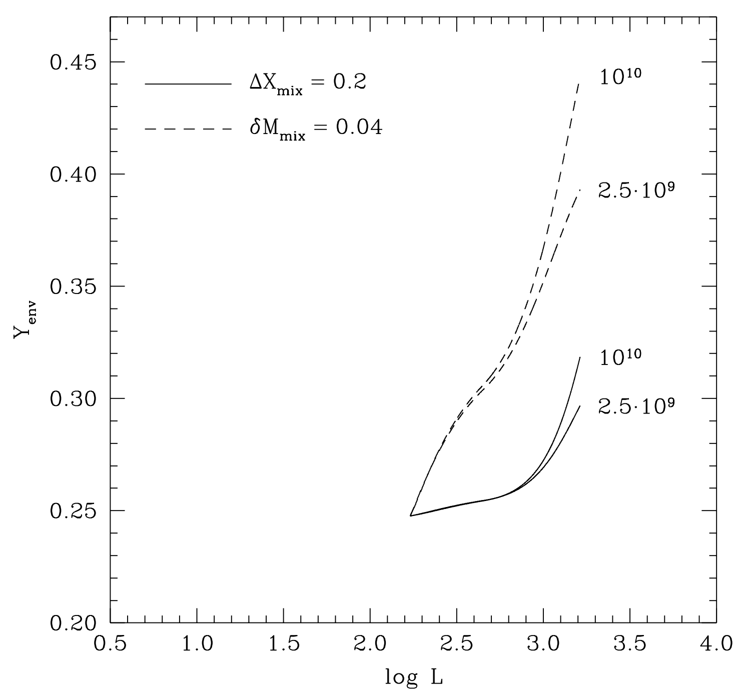

Figure 1: Evolution of the helium content of the envelope as a function of the stellar luminosity in post-processing models (initial mass $0.8M_\odot$, initial composition Y=0.25, Z=0.0003) calculated with 2 different values of the diffusive constant D_{mix} (10^{10}, 2.5^9) and of the mixing depth (ΔX_{mix}, δM_{mix}).

3 Comparison with the global O-Na anticorrelation

3.1 Constraints for the mixing mechanism

Among the chemical anomalies which have been registered over the past two decades in red giant atmospheres, the O-Na anticorrelation is one of the best tracers of the mixing mechanisms that may occur deep inside the low mass stars before the helium flash (In contradistinction, the Mg-Al anticorrelation first observed by Shetrone 1996 requires a combination of the primordial and deep mixing scenarii, as discussed in Denissenkov et al. 1998). This feature has been observed over a wide range of metallicity (-2.5<[Fe/H]<-1), in monometallic as well as in multi-metallicity globular clusters (see Figure 2). Its morphology can be explained straightforwardly within the deep mixing scenario, on which it gives an important insight. Basically, the extension of the anticorrelation along the horizontal axis depends essentially on the mixing rate times the mixing time, while its extension along the vertical axis traces the depth reached by the mixing. Indeed, on approaching the hydrogen burning shell the Na abundance experiences two distinct rises which result from proton-captures in the NeNa-cycle by ^{22}Ne and ^{20}Ne respectively (Denissenkov & Denissenkova 1990, Langer et al. 1993). The vertical extension of the anticorrelation indicates that the extra-mixing, whatever its nature, does not penetrate the second step of the Na abundance profile. The only cluster in which some giants exhibit surface enrichment produced from both ^{22}Ne and ^{20}Ne is ωCen (Norris & Da Costa 1995; see Figure 2); most of those stars with extremely high [Na/Fe] (up to 1 dex, indicating that the second rise of Na is reached by the deep mixing process) belong to the metal-rich population of ωCen. This very peculiar cluster also owns one of the bluest horizontal branches (Whitney et al. 1994).

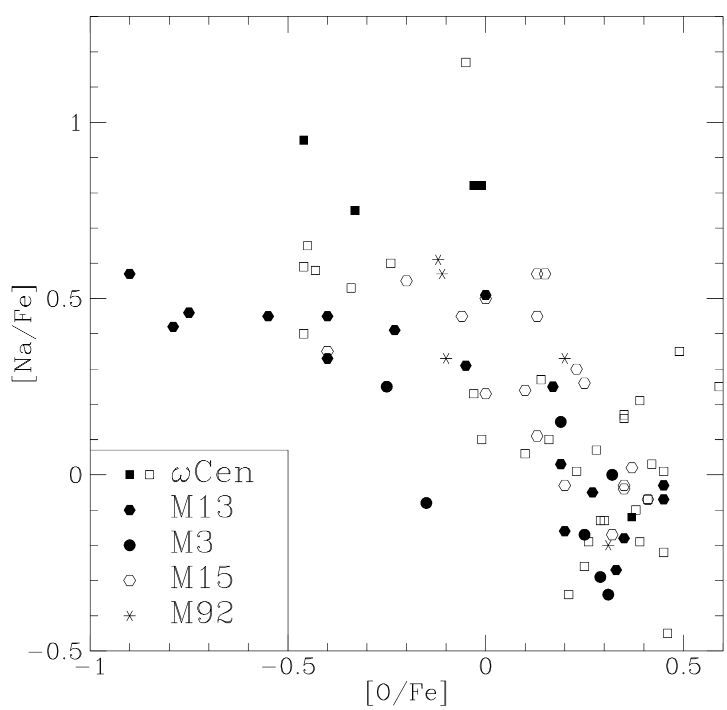

Figure 2: The global O-Na anticorrelation in several globular clusters (the black and white squares correspond to stars of ωCen with [Fe/H] respectively higher and lower than -1.0). The data are from Kraft et al. (1992, 1997), Norris & Da Costa (1995), Shetrone (1996), Sneden et al. (1997).

3.2 Predictions vs observations

In Figure 3 we compare the O-Na anticorrelation observed in three globular clusters with our predictions from models with different degrees of mixing. The models which undergo an extra-mixing leading to important helium enrichment of the envelope also exhibit Na overabundances which are never observed, except maybe in the most metal-rich giants of ωCen. In this cluster, the stars above [Na/Fe]=0.6 could be explained by shallow and long-lasting mixing; however [O/Fe]=0 is difficult to keep unless a primordial effect is added. Note that a metallicity effect (not considered here) may also play a role.

For what concerns the second parameter globular cluster M13 which presents the most extreme oxygen underabundances ([O/Fe]$\leq$-0.45), no giant shows [Na/Fe] higher than $\sim$0.5. This is in contradiction with what is expected in the models with high helium enrichment. We can conclude that the global anticorrelation rules out the possibility to get more than δY$\simeq$0.06 increase of the helium abundance in globular cluster red giants.

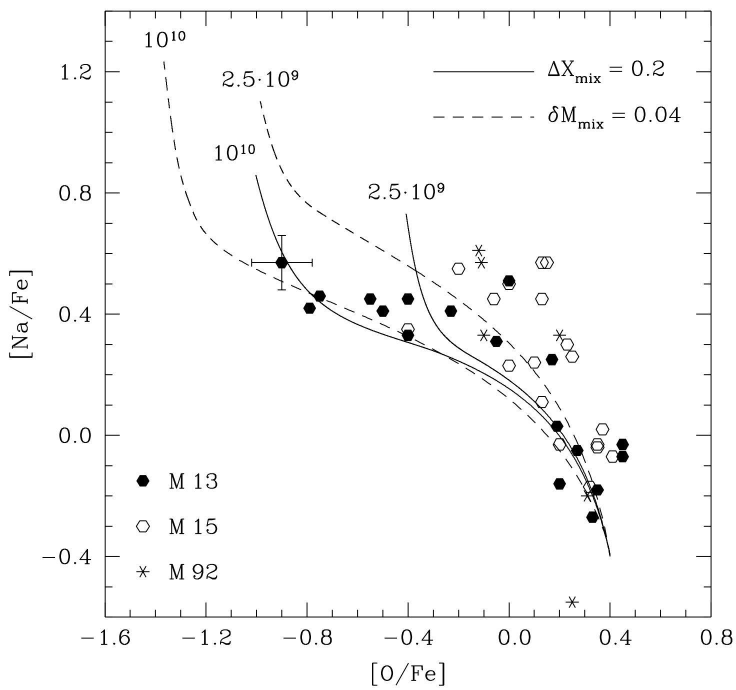

Figure 3: The global O-Na anticorrelation in the globular clusters M13, M15 and M92, and the theoretical curves obtained under the same assumptions than in Figure 1.

4 Conclusions

The global O-Na anticorrelation gives a severe constraint to the deep mixing in RGB stars. This feature can be explained by mixing which does not reach the second rise in the Na abundance profile, and thus does not lead to significant helium enrichment of the envelope. A maximum increase of the envelope helium abundance ΔY of about 0.06 only is expected. This value is much lower than ascribed by Sweigart (1997) to get a significant influence on the stellar evolution on the RGB and on the subsequent position along the HB. Models with very deep mixing and such strong helium increase predict anomalies of sodium and oxygen which are much larger than the observed ones.

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